APPENDIX D: General Guidance for Hydrologic/Hydraulic Design

The term design storm can be confusing because it is sometimes loosely used to describe volume of precipitation and runoff. These two values are related, but they are not the same. Rainfall volume is that portion of the total rainfall that does not infiltrate or evaporate.

Rainfall volume is related to runoff volume by a conversion factor, called the *runoff coefficient*. The runoff coefficient is used to calculate approximate runoff values from given rainfall values, expressed as a percentage. The general equation for conversion of rainfall to runoff is:

$$I \times R_v = Q_s$$

where: I	=	Rainfall volume (inches)
R_v	=	Runoff coefficient (dimensionless)
Q_s	=	Runoff volume (inches)

Runoff volumes can be estimated using several approaches, ranging from the simple to the more complex (and site specific). The first two approaches, the first flush of runoff and the first half-inch of runoff, are based on average runoff values developed from many years of data collection and research. Both approaches yield good working values, but are only considered averages. They do not account for site-specific variability in precipitation. The third approach, the 90-percent storm capture rule, is more site-specific.

The first flush of runoff refers more to the level of pollutant concentrations in runoff than to the volume of runoff itself. Thus, first flush is an excellent rule of thumb for sizing storm facilities for water quality purposes. The assumption follows that by capturing the first flush of pollutants, the first half-inch of runoff for a given area will be treated. Recent research indicates that the assumption does not hold true for all pollutants. This general guidance follows the first flush technique, which does have some limitations. The first flush technique is a good place to start, but some communities may have further refined requirements for sizing storm water facilities.

Sizing for Design Storms

Since not all precipitation becomes runoff, general guidance is provided to assist in determining the runoff resulting from frequency/duration/intensity of rainfall. Additional information needed are current and adjacent land uses, slope and soil types of the watershed. One of the most widely used methods for calculating runoff is the SCS methodology. The SCS methodology uses a synthetic storm distribution, Type II in Idaho. The Idaho Transportation Department (ITD) has divided the state into a number of different precipitation zones, A through I for hydraulic design purposes (Figure D-1). For example, rainfall intensities within the C zone tend to be more intense than those common to the A and B zones. Tables of land use descriptions translate the land use into curve numbers that account for most of the variables mentioned above. A set of graphs is then used to calculate the peak flows from the volume information.

The Intensity-Duration-Frequency curve used by ITD to figure storm characteristics for each zone is shown as Figures D-2. Lines showing return intervals from 2 to 100 years are drawn across a grid showing duration versus rainfall intensity. These curves show, for instance, that a 10-year, 24-hour storm, therefore, has a rainfall intensity of 0.08 inches / hour. The total volume of this storm may be calculated as 0.08 inches/hour * 24 hours = 1.92 inches. The 25-year, 24-hour storm volume is 2.4 inches.

Federal flood insurance studies use the 100-year event to determine the boundary of the flood plain. Culverts under county and state roads are usually designed for storms with a return interval of 10 or 15 years. This ensures that the road will be flooded very rarely. For smaller urban conveyance systems, benefit cost analysis has shown that the more frequent 5-year storm is often the most cost effective standard to use for storm drain design (Casamayor and Rodgers, 1980 as referenced in Debo and Reese, 1995). The configuration of natural stream channels is determined by even more frequent flows, usually the two-year event. Finally, facilities for stormwater quality control are usually sized for storms with a recurrence interval of less than a year. Although small, these storms are so numerous that controlling them will control the majority of pollutant loading within a drainage system.

Recommended Design for Water Quality Facilities

Facilities whose main purpose is water quality control generally need to detain storm flows for significantly longer periods of time than flood control facilities. Thus, to handle the same size storm, a pond to improve water quality may need to be several times the size of a facility strictly for flood control and prohibitively expensive. Therefore, facilities designed to improve water quality are usually sized using a smaller storm.

Another benefit to sizing stormwater treatment facilities for the smaller storms is that the "first flush" is captured. Pollutants tend to build up between storms and tend to be washed off during the first part of a storm. A prolonged storm may have dramatically lower pollutant concentrations towards the end than it had during the "first flush" at its start. Therefore, capturing the first few hours of a storm, for instance, may remove a greater proportion of the pollutant load than expected. The first flush effect is most commonly seen in small, highly impervious basins (e.g., an area with a large shopping mall parking lot or commercial strip development).

Ideally, several decades of storm volume and intensity information for a given county would be analyzed to determine rainfall volumes for the various design storms. The Idaho Transportation Department has done that analysis, but only for 2-year storms and larger. In order to estimate what the smaller storms are like, the Seattle area was used for comparison. The work in Seattle calculated the amount of rainfall treated by capturing different sized, 24-hour duration storms (Puget Sound manual, 1992). The study found that 98 percent of the rainfall fell in storms equal to or smaller than the 2-year storm. The 1-year storm encompassed 95 percent of the total rainfall. Storms of 6-month or smaller size accounted for 91 percent of the rainfall. One-month storms accounted for 62 percent of the rainfall.

As one might expect, the pond size required to capture these storm volumes escalates rapidly as the storms grow larger. The 1-month storm volume from 1 urban acre was estimated as 1000 cubic feet. The pond requires 3000, 4010, and 5380 cubic feet respectively for the 6-month, 1-year, and 2-year storms. In other words, the required volume triples from the 1-month to the 6-month storm while capturing an additional 29 percent of the stormwater runoff. Increasing the pond by an additional third, 3000 to 4010 cubic feet increases the capture by an additional 4 percent.

Thus, although an ideal situation might be to capture and treat all stormwater runoff, it is obvious that the size, and therefore, cost of the facilities required would quickly become prohibitive. The point at which the pond is the most cost-efficient appears to lie somewhere in between the 1 and 6-month return frequencies.

Estimating the appropriate water quality storm volume can be problematic. The Intensity/Duration/Frequency curves given in the Figures D-2 only go down to the 2-year storm. For the Seattle area, the 6-month 24-hour storm was found to be 64 percent of the 2-year storm. However, the most efficient volume appears to be somewhat less than this. Thus, 1/3 of the 2-year storm volume is recommended. LOCAL DESIGN STANDARDS FOR SIZING STORMWATER FACILITIES FOR WATER QUALITY SHOULD BE USED IF THEY EXIST.

Recommended Design for Flood Control Facilities

In areas about to be developed, the most commonly used method for sizing facilities to control flooding is to compare pre-development runoff with projected post-development runoff. The developer is then responsible for the difference. For example, a new subdivision of single-family residential 1/2-acre lots is to be created from an existing ranch. Modeling shows that the estimated peak flow from the ranch during a 10-year storm is 40 cfs. After development, the projected flow will be 320 cfs. The developer is responsible for the additional 280 cfs. He may provide on-site detention of adequate volume to maintain the peak flow at the existing 40 cfs. He may contribute in-lieu of fees towards a regional detention facility which would decrease flows from his development and adjacent ones. Or he may help pay for the increased culvert sizes and ditches necessary to carry the excess flows.

LOCAL DESIGN STANDARDS FOR SIZING STORMWATER FACILITIES FOR FLOOD CONTROL SHOULD BE USED IF THEY EXIST. If no local standards are presently in use, the recommended storm for sizing conveyance facilities affecting major streets is the 10-year storm. The 5-year storm is recommended for smaller, residential streets where traffic density is lighter.

Estimating Runoff During Snowmelt

Most stormwater facilities are designed for design storms which are usually assumed to consist of precipitation entirely in the form of rain. In most parts of the country the largest storms are intense summer thunderstorms. In the Pacific Northwest the largest rainfall volumes occur in less-intense, but prolonged winter storms. A different type of event that often contributes to flooding is snowmelt, especially in conjunction with a rainstorm. One characteristic that makes snowmelt so damaging is that the heavy flows are not lessened by absorption into ground that is saturated and frozen. Due to the significant amount of water tied up in the snowpack, snowmelt can cause significant capacity and erosion problems. This problem is worsened if a significant rain event occurs during the melt when the ground is still frozen.

Flows occurring during snowmelt are difficult to estimate. As one of the bulleted items under Limitations on page 2-11 of the TR-55 Manual contained in this appendix states, "Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures." However, the application of a formula derived from another source, in conjunction with an adjustment in the TR-55 method allows at least a rough estimate to be made of flows occurring during snowmelt.

As stated above, the heaviest runoff in springtime often occurs during snowmelt when an intense rainstorm occurs when the ground is still frozen. All three factors must be considered to arrive at an estimate of the resulting flow.

First, the storm should be derived from the Intensity/Duration/Frequency curves in the same manner as the regular design storm. (Since the IDF curves represent the greatest intensity expected during a given time period and since this usually occurs during summer thunderstorms, assuming that this storm intensity occurs during snowmelt is being quite conservative.)

Second, the CN number should be adjusted. The CN numbers given for the various land uses in the tables in this appendix are for an antecedent moisture condition of II. An AMC of II is defined as average conditions. The table below should be used to convert these AMC II numbers to those of AMC III. AMC III is defined as heavy rainfall, or light rainfall and low temperatures occurring within the last five days, leading to saturated soils.

Third, the water contributed from the snowmelt itself needs to be computed. The Degree-Day Method outlined in the HEC-1 model developed by the Army Corps of Engineers is recommended for making this estimate.

The Degree-Day Method is based on the following equation:

SNWMT = COEF (TMPR - FRZTP)

where SNWMT is the melt in inches per day,
TMPR is the air temperature in degrees F,
FRZTP is the temperature in degrees F at which snow melts,
and COEF is the melt coefficient in inches per degree-day, usually about 0.07.

Assuming the worst conditions, a sudden thaw of 40 degrees, the snowmelt = 0.07 (40-32) or 0.56 inches/day. This should be added to the rainfall from the storm and used in conjunction with the increased CN read from the table below.

Future Revision

As additional information on storm characteristics becomes available, the water quality design storm definition may be revised. A statistical analysis of total capture volume for up to a 1-year storm, proceeding in monthly increments, should allow a curve of capture efficiency to be plotted and used to refine the required storm capture volume.

The sections following the references are taken from the TR55 manual published by the SCS in 1986. The use of the excerpts is to assist and provide general guidance for sizing storm water facilities. They are recommended for calculating stormwater volumes and peak flows for stormwater BMP design. CONSULT THE LOCAL PERMITTING AUTHORITY TO DETERMINE WHETHER THERE ARE ADDITIONAL REQUIREMENTS OR PREFERRED ALTERNATIVES FOR SIZING STORM DESIGNS. LOCAL DESIGN STANDARDS SHOULD BE USED IF THEY EXIST.

References

Brown and Caldwell, 1997, Handbook of Valley County Stormwater BMPs.

Casamayor, JE and JR Rodgers. Cost Analysis of 2-year, 5-year and 10-year Stormwater Protection. San Antonio, Texas: Hydraulics Technical Group, Texas Section, ASCE.

Debo, TN and AJ Reese. 1995. Municipal Storm Water Management. Ann Arbor: Lewis Publishers.

State of Washington Department of Ecology. 1992. Stormwater Management Manual for the Puget Sound Basin.

Terrene Institute, 1996, A Watershed Approach to Urban Runoff: Handbook for Decisionmakers.

Table for Converting AMC II to AMC III.

CN for condition II	CN for condition III	CN for condition II	CN for condition III
100	100	62	79
99	100	61	78
98	99	60	78
97	99	59	77
96	99	58	76
95	98	57	75
94	98	56	75
93	98	55	74
92	97	54	73
91	97	53	72
90	96	52	71
89	96	51	70
88	95	50	70
87	95	49	69
86	94	48	68
85	94	47	67
84	93	46	66
83	93	45	65
82	92	44	64
81	92	43	63
80	91	42	62
79	91	41	61
78	90	40	60
77	89	39	59
76	89	38	58
75	88	37	57
74	88	36	56
73	87	35	55
72	86	34	54
71	86	33	53
70	85	32	52
69	84	31	51
68	84	30	50
67	83	25	43
66	82	20	37
65	82	15	30
64	81	10	22
63	80	5	13

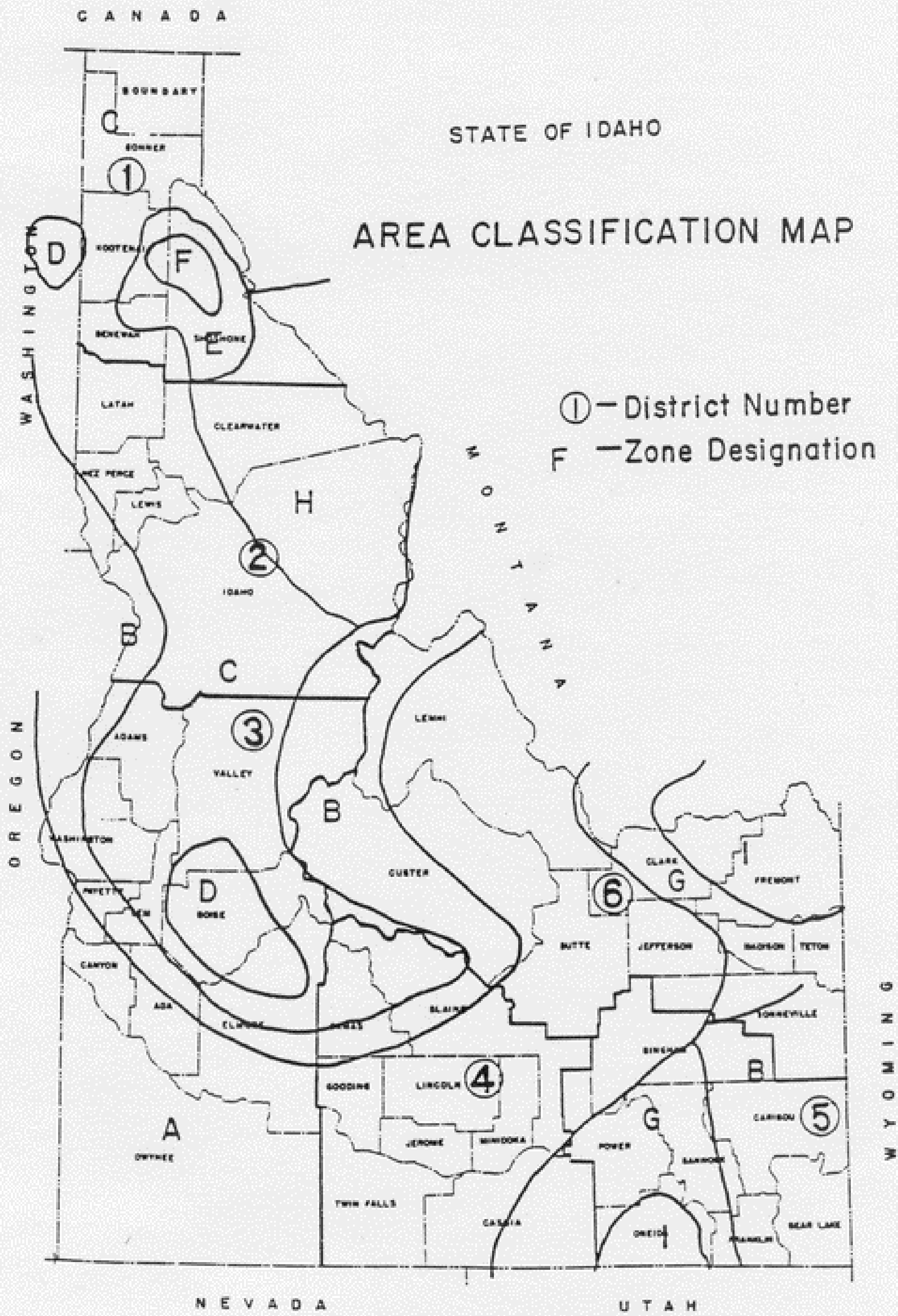


Figure D-1. State of Idaho Area Classification Map

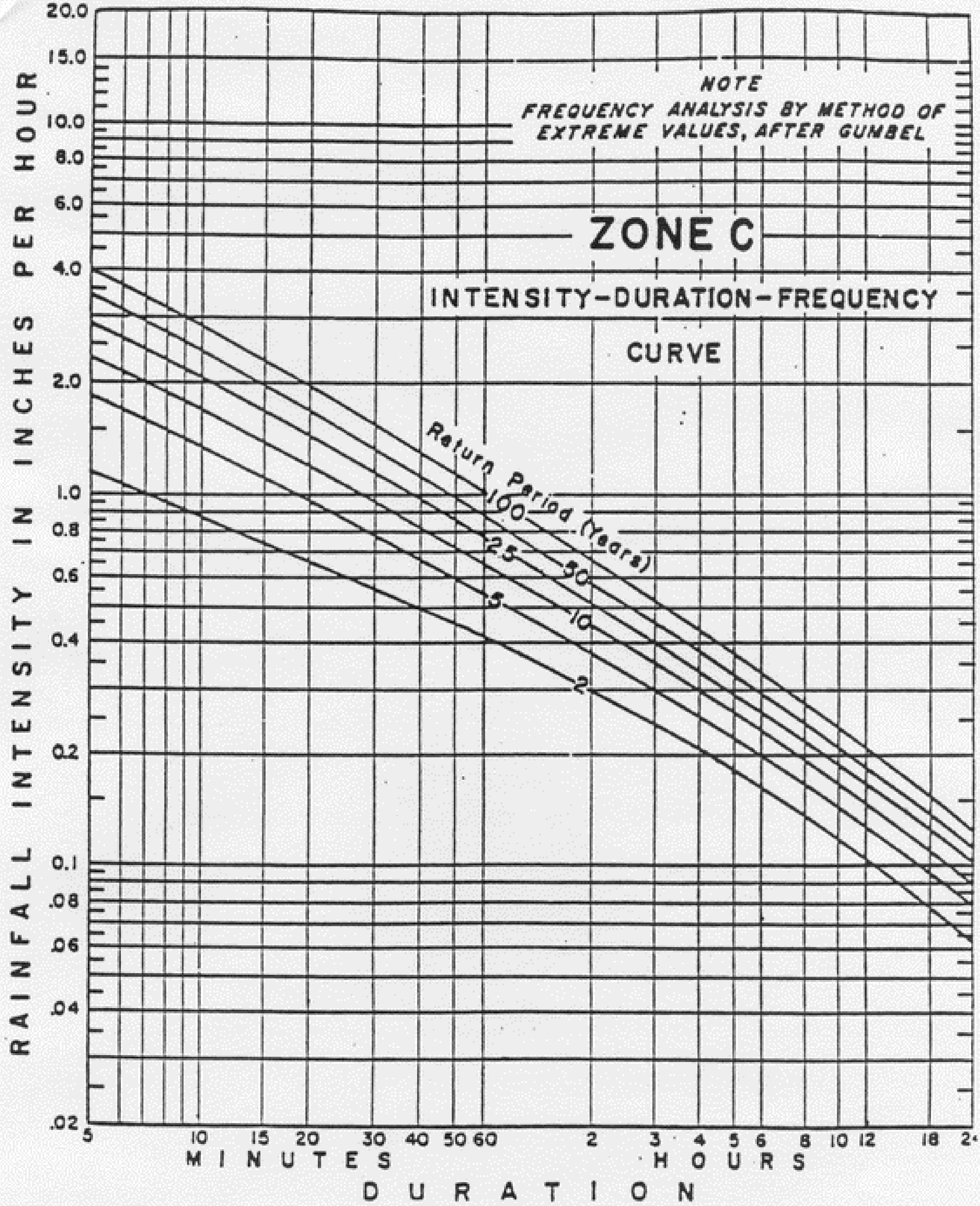
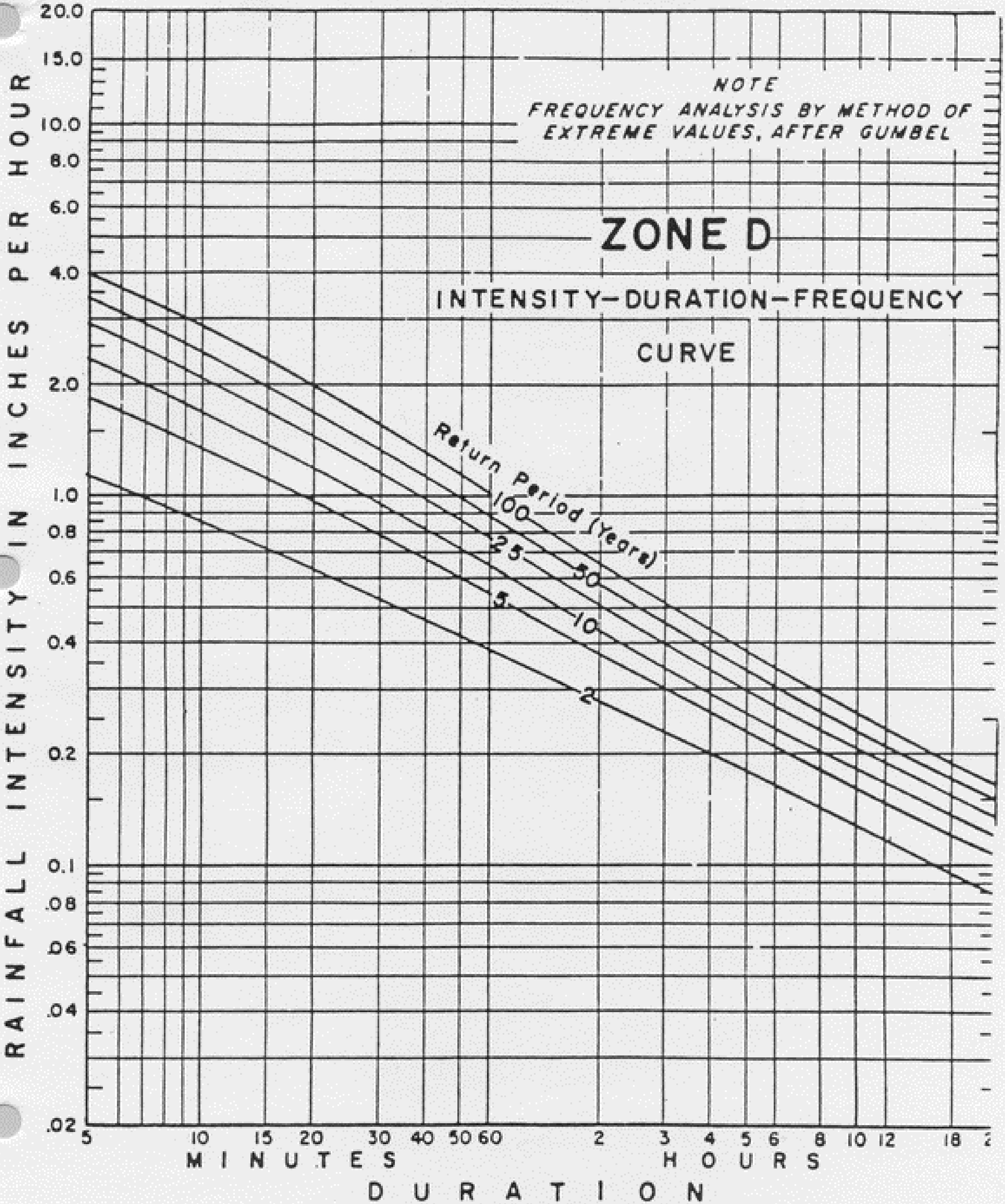
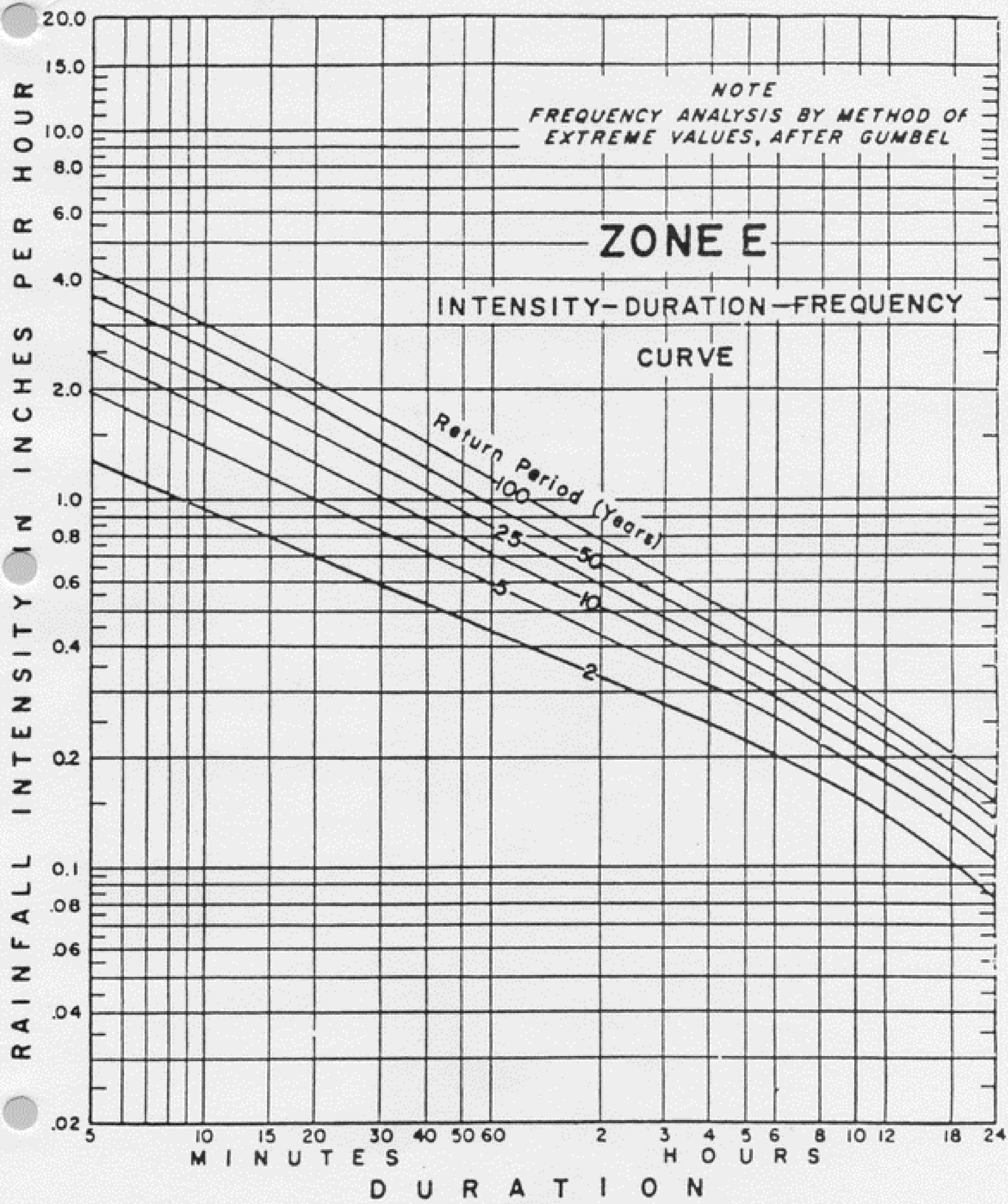


Figure D-2. Zone C Intensity-Duration-Frequency (IDF) Curve

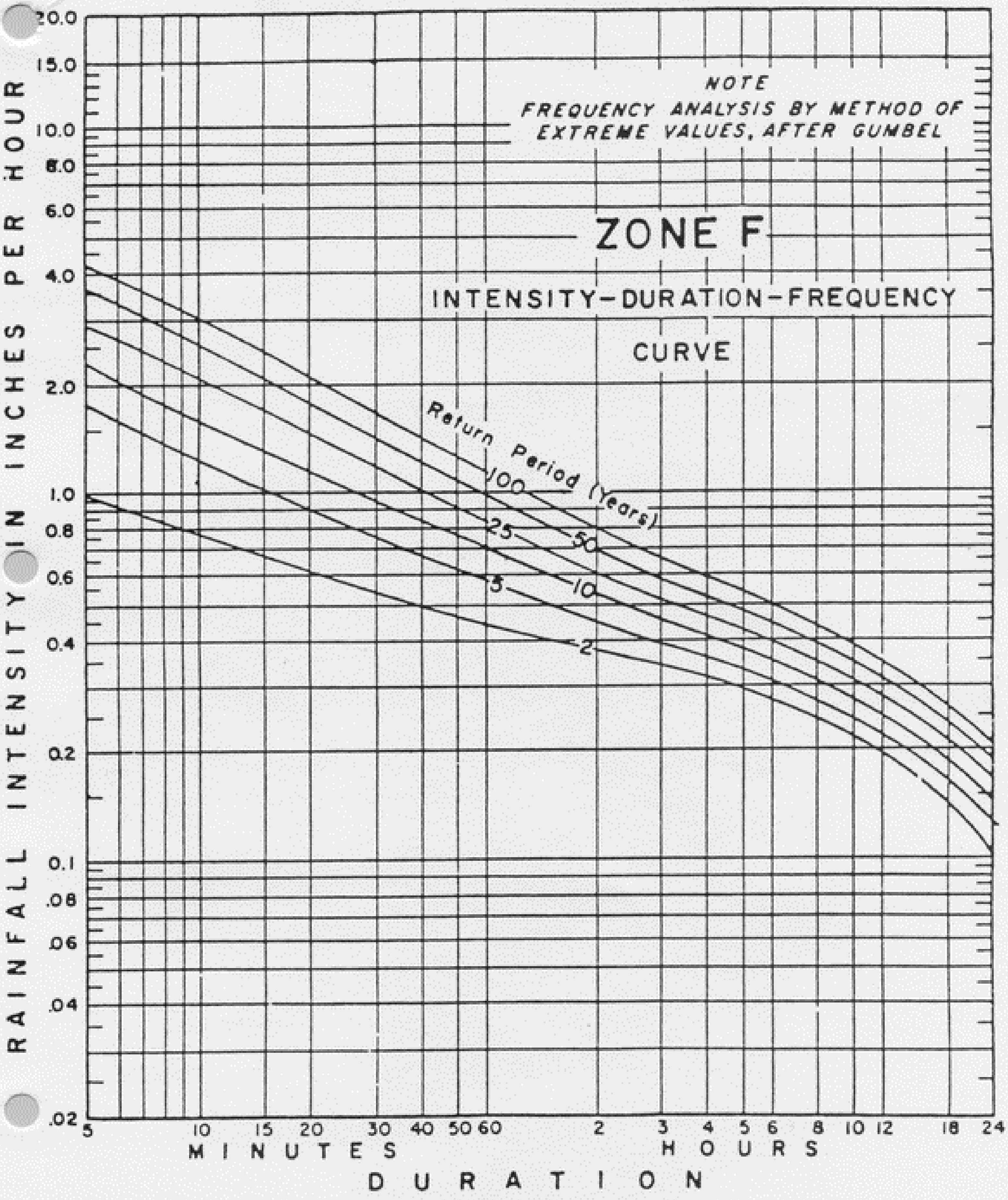
ZONE D, INTENSITY-DURATION-FREQUENCY CURVE
(IDAHO TRANSPORTATION DEPARTMENT)



ZONE E, INTENSITY-DURATION-FREQUENCY CURVE
(IDAHO TRANSPORTATION DEPARTMENT)



ZONE F, INTENSITY-DURATION-FREQUENCY CURVE
(IDAHO TRANSPORTATION DEPARTMENT)



Calculating Storm Water Volumes and Peak Flows

The following is an excerpt from the TR55 manual published by the Soil Conservation Service (now called the Natural Resources Conservation Service) in 1986. The procedures can be used for calculating stormwater runoff volumes and peak flows for BMP design.

Chapter 2: Estimating runoff

SCS Runoff Curve Number method

The SCS Runoff Curve Number (CN) method is described in detail in NEH-4 (SCS 1985). The SCS runoff equation is

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{[Eq. 2-1]}$$

where

Q = runoff (in),
P = rainfall (in),
S = potential maximum retention after runoff begins (in), and
I_a = initial abstraction (in).

Initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, I_a was found to be approximated by the following empirical equation:

$$I_a = 0.2S. \qquad \text{[Eq. 2-2]}$$

By removing I_a as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Substituting equation 2-2 into equation 2-1 gives

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}. \qquad \text{[Eq. 2-3]}$$

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by

$$S = \frac{1000}{CN} - 10. \qquad \text{[Eq. 2-4]}$$

Figure 2-1 and table 2-1 solve equations 2-3 and 2-4 for a range of CN's and rainfall.

Factors considered in determining runoff curve numbers

The major factors that determine CN are the hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent runoff condition (ARC). Another factor considered is whether impervious areas outlet directly to the drainage system (connected) or whether the flow spreads over pervious areas before entering the drainage system (unconnected). Figure 2-2 is provided to aid in selecting the appropriate figure or table for determining curve numbers.

CN's in table 2-2 (*a* to *d*) represent average antecedent runoff condition for urban, cultivated agricultural, other agricultural, and arid and semiarid rangeland uses. Table 2-2 assumes impervious areas are directly connected. The following sections explain how to determine CN's and how to modify them for urban conditions.

Hydrologic soil groups

Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. Soils are classified into four HSG's (A, B, C, and D) according to their minimum infiltration rate, which is obtained for bare soil after prolonged wetting. Appendix A defines the four groups and provides a list of most of the soils in the United States and their group classification. The soils in the area of interest may be identified from a soil survey report, which can be obtained from local SCS offices or soil and water conservation district offices.

Most urban areas are only partially covered by impervious surfaces: the soil remains an important factor in runoff estimates. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (sands and gravels) than in watersheds predominantly of silts and clays, which generally have low infiltration rates.

Any disturbance of a soil profile can significantly change its infiltration characteristics. With urbanization, native soil profiles may be mixed or removed or fill material from other areas may be introduced. Therefore, a method based on soil

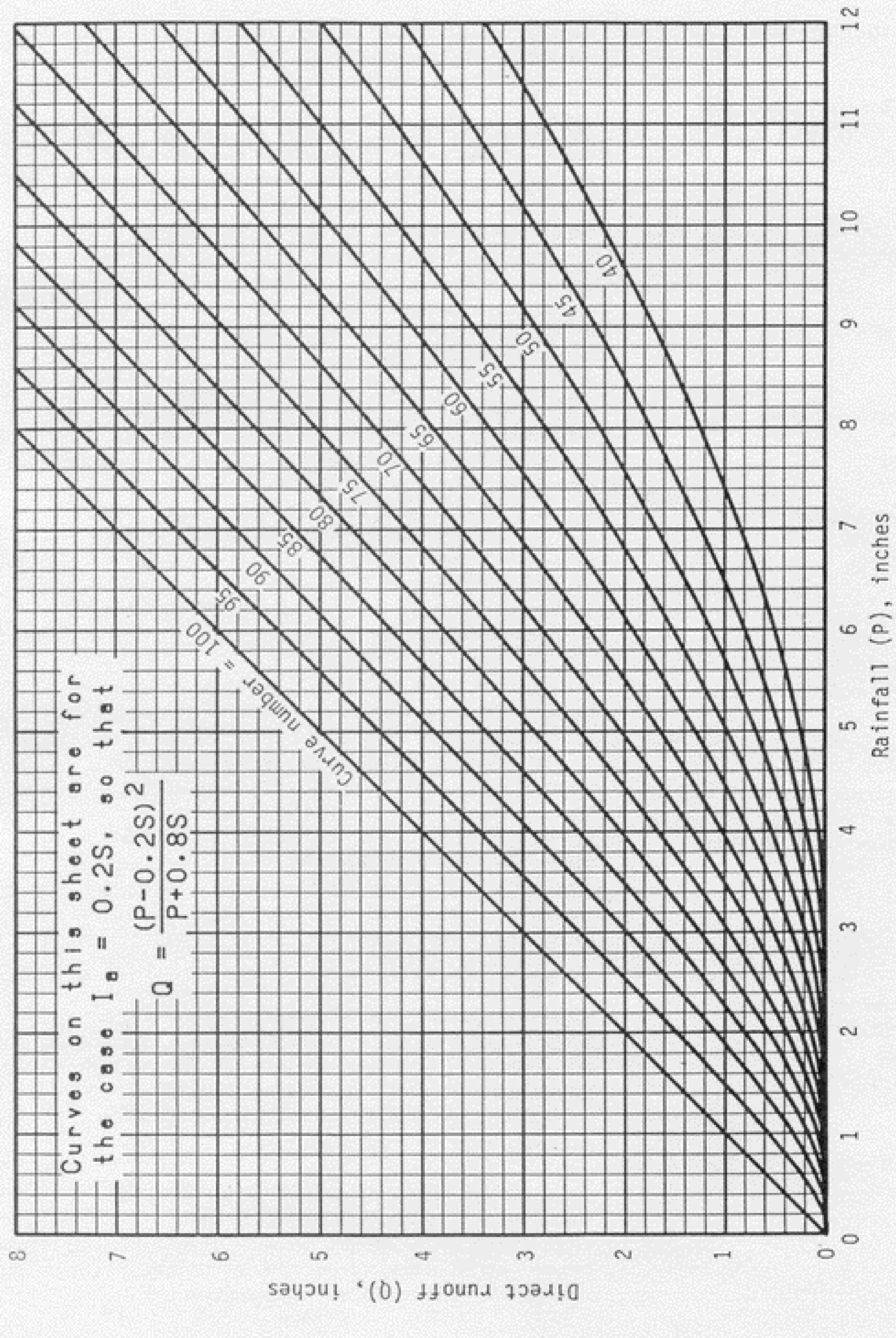


Figure 2-1.—Solution of runoff equation.

texture is given in appendix A for determining the HSG classification for disturbed soils.

Cover type

Table 2-2 addresses most cover types, such as vegetation, bare soil, and impervious surfaces. There are a number of methods for determining cover type. The most common are field reconnaissance, aerial photographs, and land use maps.

Treatment

Treatment is a cover type modifier (used only in table 2-2b) to describe the management of cultivated agricultural lands. It includes mechanical practices, such as contouring and terracing, and management practices, such as crop rotations and reduced or no tillage.

Hydrologic condition

Hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. *Good* hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type, and treatment. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops, or other vegetative areas; (b) amount of year-round cover; (c) amount of grass or close-seeded legumes in rotations; (d) percent of residue cover; and (e) degree of surface roughness.

Table 2-1.—Runoff depth for selected CN's and rainfall amounts[1]

	Runoff depth for curve number of—												
Rainfall	40	45	50	55	60	65	70	75	80	85	90	95	98
							inches						
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1]Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

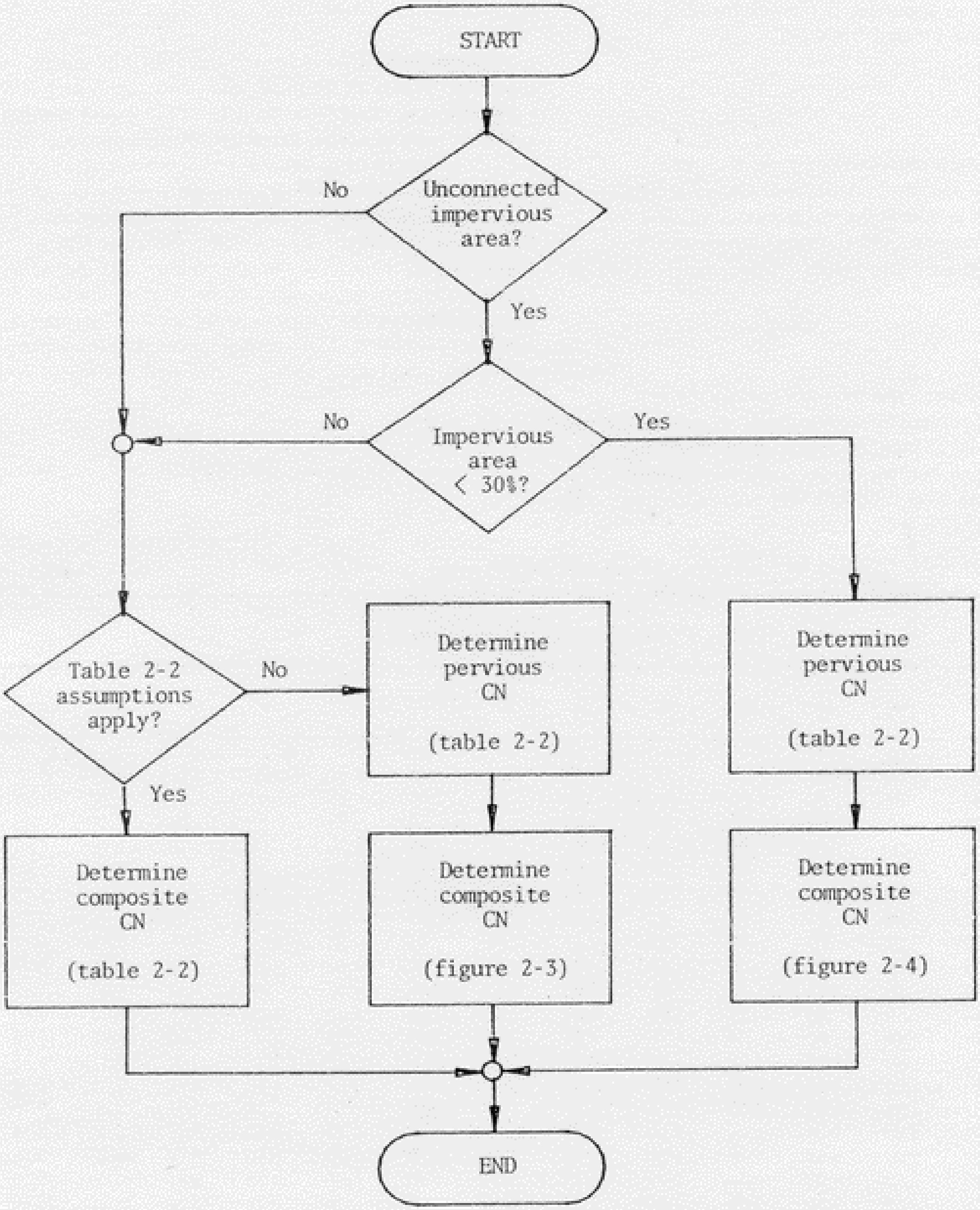


Figure 2-2.—Flow chart for selecting the appropriate figure or table for determining runoff curve numbers.

Table 2-2a.—Runoff curve numbers for urban areas[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1]Average runoff condition, and $I_a = 0.2S$.
[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
[3]CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
[4]Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
[5]Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 2-2b.—Runoff curve numbers for cultivated agricultural lands[1]

Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1]Average runoff condition, and $I_a = 0.2S$.
[2]*Crop residue cover* applies only if residue is on at least 5% of the surface throughout the year.
[3]Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good $\geq$ 20%), and (e) degree of surface roughness.
Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 2-2c.—Runoff curve numbers for other agricultural lands[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
Woods—grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1]Average runoff condition, and $I_a = 0.2S$.

[2]*Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3]*Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4]Actual curve number is less than 30; use CN = 30 for runoff computations.

[5]CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6]*Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table 2-2d.—Runoff curve numbers for arid and semiarid rangelands[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition[2]	A[3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1]Average runoff condition, and $I_a = 0.2S$. For range in humid regions, use table 2-2c.

[2]*Poor:* <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.

[3]Curve numbers for group A have been developed only for desert shrub.

Antecedent runoff condition

The index of runoff potential before a storm event is the antecedent runoff condition (ARC). ARC is an attempt to account for the variation in CN at a site from storm to storm. CN for the average ARC at a site is the median value as taken from sample rainfall and runoff data. The CN's in table 2-2 are for the average ARC, which is used primarily for design applications. See NEH-4 (SCS 1985) and Rallison and Miller (1981) for more detailed discussion of storm-to-storm variation and a demonstration of upper and lower enveloping curves.

Urban impervious area modifications

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for urban areas (Rawls et al., 1981). For example, do the impervious areas connect directly to the drainage system, or do they outlet onto lawns or other pervious areas where infiltration can occur?

Connected impervious areas

An impervious area is considered connected if runoff from it flows directly into the drainage system. It is also considered connected if runoff from it occurs as concentrated shallow flow that runs over a pervious area and then into a drainage system.

Urban CN's (table 2-2a) were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that (a) pervious urban areas are equivalent to pasture in good hydrologic condition and (b) impervious areas have a CN of 98 and are directly connected to the drainage system. Some assumed percentages of impervious area are shown in table 2-2a.

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in table 2-2a are not applicable, use figure 2-3 to compute a composite CN. For example, table 2-2a gives a CN of 70 for a ½-acre lot in HSG B, with an assumed impervious area of 25 percent. However, if the lot has 20 percent impervious area and a pervious area CN of 61, the composite CN obtained from figure 2-3 is 68. The CN difference between 70 and 68 reflects the difference in percent impervious area.

Unconnected impervious areas

Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, (1) use figure 2-4 if total impervious area is less than 30 percent or (2) use figure 2-3 if the total impervious area is equal to or greater than 30 percent, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

When impervious area is less than 30 percent, obtain the composite CN by entering the right half of figure 2-4 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a ½-acre lot with 20 percent total impervious area (75 percent of which is unconnected) and pervious CN of 61, the composite CN from figure 2-4 is 66. If all of the impervious area is connected, the resulting CN (from figure 2-3) would be 68.

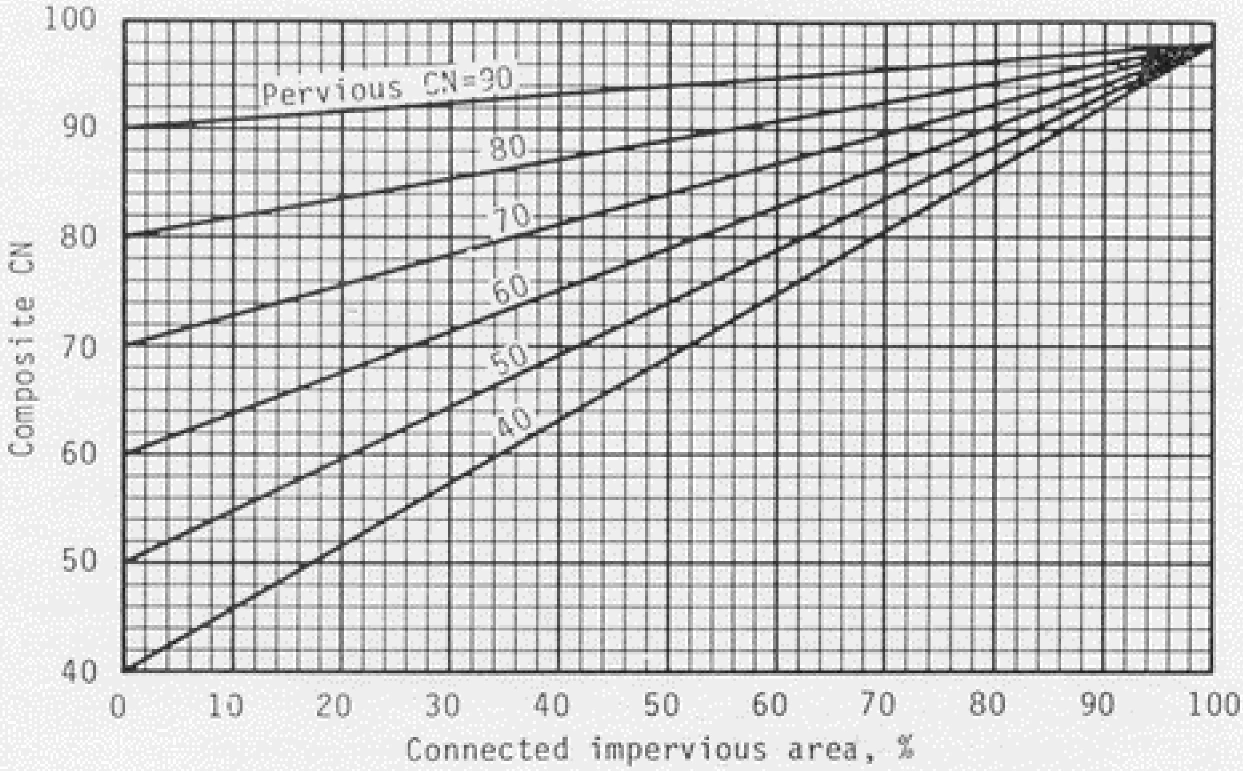


Figure 2-3.—Composite CN with connected impervious area.

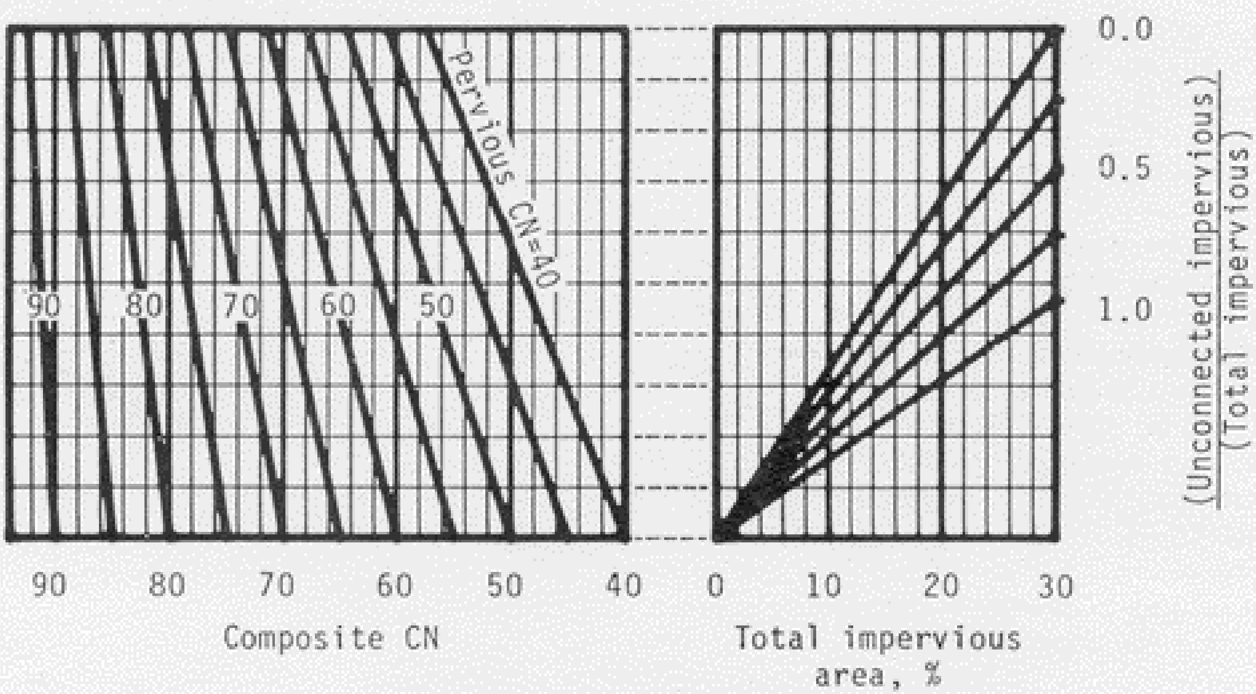


Figure 2-4.—Composite CN with unconnected impervious areas and total impervious area less than 30%.

Runoff

When CN and the amount of rainfall have been determined for the watershed, determine runoff by using figure 2-1, table 2-1, or equations 2-3 and 2-4. The runoff is usually rounded to the nearest hundredth of an inch.

Limitations

- Curve numbers describe average conditions that are useful for design purposes. If the rainfall event used is a historical storm, the modeling accuracy decreases.

- Use the runoff curve number equation with caution when recreating specific features of an actual storm. The equation does not contain an expression for time and, therefore, does not account for rainfall duration or intensity.

- The user should understand the assumption reflected in the initial abstraction term (I_a) and should ascertain that the assumption applies to the situation. I_a, which consists of interception, initial infiltration, surface depression storage, evapotranspiration, and other factors, was generalized as 0.2S based on data from agricultural watersheds (S is the potential maximum retention after runoff begins). This approximation can be especially important in an urban application because the combination of impervious areas with pervious areas can imply a significant initial loss that may not take place. The opposite effect, a greater initial loss, can occur if the impervious areas have surface depressions that store some runoff. To use a relationship other than $I_a = 0.2S$, one must redevelop equation 2-3, figure 2-1, table 2-1, and table 2-2 by using the original rainfall-runoff data to establish new S or CN relationships for each cover and hydrologic soil group.

- Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures.

- The CN procedure is less accurate when runoff is less than 0.5 inch. As a check, use another procedure to determine runoff.

- The SCS runoff procedures apply only to direct surface runoff: do not overlook large sources of subsurface flow or high ground water levels that contribute to runoff. These conditions are often related to HSG A soils and forest areas that have been assigned relatively low CN's in table 2-2. Good judgment and experience based on stream gage records are needed to adjust CN's as conditions warrant.

- When the weighted CN is less than 40, use another procedure to determine runoff.

Examples

Four examples illustrate the procedure for computing runoff curve number (CN) and runoff (Q) in inches. Worksheet 2 in appendix D is provided to assist TR-55 users. Figures 2-5 to 2-8 represent the use of worksheet 2 for each example. All four examples are based on the same watershed and the same storm event.

The watershed covers 250 acres in Dyer County, northwestern Tennessee. Seventy percent (175 acres) is a Loring soil, which is in hydrologic soil group C. Thirty percent (75 acres) is a Memphis soil, which is in group B. The event is a 25-year frequency, 24-hour storm with total rainfall of 6 inches.

Cover type and conditions in the watershed are different for each example. The examples, therefore, illustrate how to compute CN and Q for various situations of proposed, planned, or present development.

Example 2-1

The present cover type is pasture in good hydrologic condition. (See figure 2-5 for worksheet 2 information.)

Example 2-2

Seventy percent (175 acres) of the watershed, consisting of all the Memphis soil and 100 acres of the Loring soil, is ½-acre residential lots with lawns in good hydrologic condition. The rest of the watershed is scattered open space in good hydrologic condition. (See figure 2-6.)

Example 2-3

This example is the same as example 2-2, except that the ½-acre lots have a total impervious area of 35 percent. For these lots, the pervious area is lawns in good hydrologic condition. Since the impervious area percentage differs from the percentage assumed in table 2-2, use figure 2-3 to compute CN. (See figure 2-7.)

Example 2-4

This example is also based on example 2-2, except that 50 percent of the impervious area associated with the ½-acre lots on the Loring soil is "unconnected," that is, it is not directly connected to the drainage system. For these lots, the pervious area CN (lawn, good condition) is 74 and the impervious area is 25 percent. Use figure 2-4 to compute the CN for these lots. CN's for the ½-acre lots on Memphis soil and the open space on Loring soil are the same as those in example 2-2. (See figure 2-8.)

Worksheet 2: Runoff curve number and runoff

Project Heavenly Acres By WJR Date 10/1/85

Location Dyer County, Tennessee Checked JKM Date 10/3/85

Circle one: Present Developed

1. Runoff curve number (CN)

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 2-2	CN 1/ Fig. 2-3	CN 1/ Fig. 2-4	Area ☐acres ☐mi² ☒%	Product of CN x area
Memphis, B	Pasture, good condition	61			30	1830
Loring, C	Pasture, good condition	74			70	5180
				Totals =	100	7010

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{7010}{100} = 70.1$; Use CN = $\boxed{70}$

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	6.0		
Runoff, Q (Use P and CN with table 2-1, fig. 2-1, or eqs. 2-3 and 2-4.)	in	2.81		

Figure 2-5.—Worksheet 2 for example 2-1.

Worksheet 2: Runoff curve number and runoff

Project Heavenly Acres By WJR Date 10/1/85

Location Dyer County, Tennessee Checked NM Date 10/3/85

Circle one: Present Developed 175 acres residential

1. Runoff curve number (CN)

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1/] Table 2-2	CN [1/] Fig. 2-3	CN [1/] Fig. 2-4	Area ☒ acres ☐ mi^2 ☐ %	Product of CN x area
Memphis, B	25% impervious ½ acre lots, good condition	70			75	5250
Loring, C	25% impervious ½ acre lots, good condition	80			100	8000
Loring, C	Open space, good condition	74			75	5550
				Totals =	250	18,800

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{18,800}{250} = 75.2$; Use CN = $\boxed{75}$

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	6.0		
Runoff, Q (Use P and CN with table 2-1, fig. 2-1, or eqs. 2-3 and 2-4.)	in	3.28		

Figure 2-6.—Worksheet 2 for example 2-2.

Worksheet 2: Runoff curve number and runoff

Project Heavenly Acres By WJR Date 10/1/85

Location Dyer County, Tennessee Checked NM Date 10/3/85

Circle one: Present Developed

1. Runoff curve number (CN)

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1/] Table 2-2	CN [1/] Fig. 2-3	CN [1/] Fig. 2-4	Area ☒ acres ☐ mi^2 ☐ %	Product of CN x area
Memphis, B	35% impervious ½ acre lots, good condition		74		75	5550
Loring, C	35% impervious ½ acre lots, good condition		82		1000	8200
Loring, C	Open space, good condition	74			75	5550
				Totals =	250	19,300

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{19{,}300}{250} = 77.2$; Use CN = $\boxed{77}$

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	6.0		
Runoff, Q .... (Use P and CN with table 2-1, fig. 2-1, or eqs. 2-3 and 2-4.)	in	3.48		

Figure 2-7.—Worksheet 2 for example 2-3.

Worksheet 2: Runoff curve number and runoff

Project Heavenly Acres By WJR Date 10/1/85

Location Dyer County, Tennessee Checked NM Date 10/3/85

Circle one: Present Developed

1. Runoff curve number (CN)

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1/] Table 2-2	CN [1/] Fig. 2-3	CN [1/] Fig. 2-4	Area ☒ acres ☐ mi^2 ☐ %	Product of CN x area
Memphis, B	25% connected impervious 1/2 acre lots, good condition	70			75	5250
Loring, C	25% impervious with 50% unconnected 1/2 acre lots, good condition			78	100	7800
Loring, C	Open space, good condition	74			75	5550
				Totals =	250	18,600

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{18{,}600}{250} = 74.4$; Use CN = $\boxed{74}$

2. Runoff

	Storm #1	Storm #2	Storm #3
Frequency .... yr	25		
Rainfall, P (24-hour) .... in	6.0		
Runoff, Q .... in (Use P and CN with table 2-1, fig. 2-1, or eqs. 2-3 and 2-4.)	3.19		

Figure 2-8.—Worksheet 2 for example 2-4.

Chapter 3: Time of concentration and travel time

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. T_t is a component of time of concentration (T_c), which is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system.

T_c influences the shape and peak of the runoff hydrograph. Urbanization usually decreases T_c, thereby increasing the peak discharge. But T_c can be increased as a result of (a) ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts, or (b) reduction of land slope through grading.

Factors affecting time of concentration and travel time

Surface roughness

One of the most significant effects of urban development on flow velocity is less retardance to flow. That is, undeveloped areas with very slow and shallow overland flow through vegetation become modified by urban development: the flow is then delivered to streets, gutters, and storm sewers that transport runoff downstream more rapidly. Travel time through the watershed is generally decreased.

Channel shape and flow patterns

In small non-urban watersheds, much of the travel time results from overland flow in upstream areas. Typically, urbanization reduces overland flow lengths by conveying storm runoff into a channel as soon as possible. Since channel designs have efficient hydraulic characteristics, runoff flow velocity increases and travel time decreases.

Slope

Slopes may be increased or decreased by urbanization, depending on the extent of site grading or the extent to which storm sewers and street ditches are used in the design of the water management system. Slope will tend to increase when channels are straightened and decrease when overland flow is directed through storm sewers, street gutters, and diversions.

Computation of travel time and time of concentration

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type that occurs is a function of the conveyance system and is best determined by field inspection.

Travel time (T_t) is the ratio of flow length to flow velocity:

$$T_t = \frac{L}{3600\ V} \qquad \text{[Eq. 3-1]}$$

where

T_t = travel time (hr),
L = flow length (ft),
V = average velocity (ft/s), and
3600 = conversion factor from seconds to hours.

Time of concentration (T_c) is the sum of T_t values for the various consecutive flow segments:

$$T_c = T_{t_1} + T_{t_2} + \ldots T_{t_m} \qquad \text{[Eq. 3-2]}$$

where

T_c = time of concentration (hr) and
m = number of flow segments.

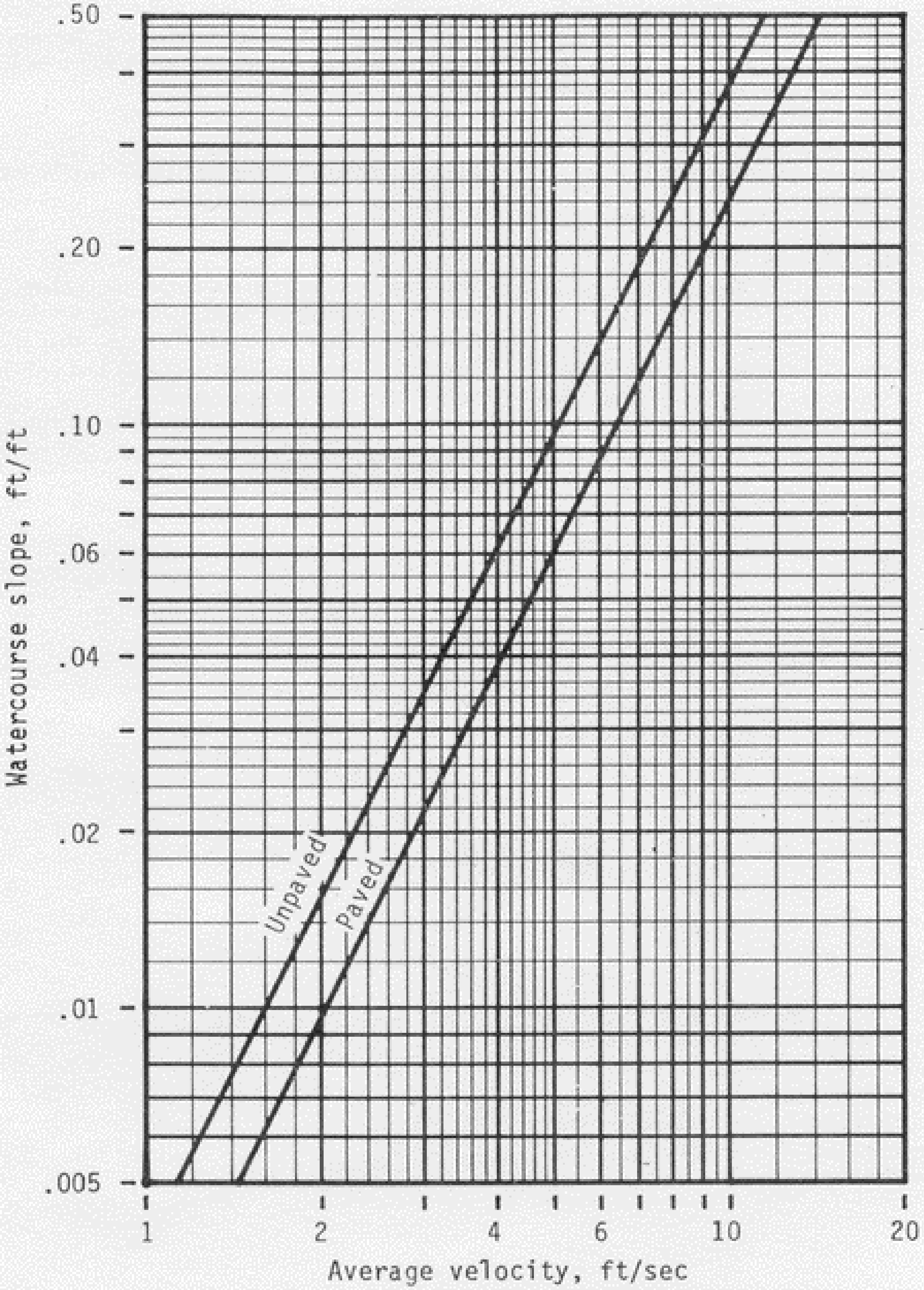


Figure 3-1.—Average velocities for estimating travel time for shallow concentrated flow.

Sheet flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. These n values are for very shallow flow depths of about 0.1 foot or so. Table 3-1 gives Manning's n values for sheet flow for various surface conditions.

For sheet flow of less than 300 feet, use Manning's kinematic solution (Overton and Meadows 1976) to compute T_t:

$$T_t = \frac{0.007\,(nL)^{0.8}}{(P_2)^{0.5}\,s^{0.4}} \qquad \text{[Eq. 3-3]}$$

Table 3-1.—Roughness coefficients (Manning's n) for sheet flow

Surface description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1]The n values are a composite of information compiled by Engman (1986).
[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3]When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

where

T_t = travel time (hr),
n = Manning's roughness coefficient (table 3-1),
L = flow length (ft),
P_2 = 2-year, 24-hour rainfall (in), and
s = slope of hydraulic grade line (land slope, ft/ft).

This simplified form of the Manning's kinematic solution is based on the following: (1) shallow steady uniform flow, (2) constant intensity of rainfall excess (that part of a rain available for runoff), (3) rainfall duration of 24 hours, and (4) minor effect of infiltration on travel time. Rainfall depth can be obtained from appendix B.

Shallow concentrated flow

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from figure 3-1, in which average velocity is a function of watercourse slope and type of channel. For slopes less than 0.005 ft/ft, use equations given in appendix F for figure 3-1. Tillage can affect the direction of shallow concentrated flow. Flow may not always be directly down the watershed slope if tillage runs across the slope.

After determining average velocity in figure 3-1, use equation 3-1 to estimate travel time for the shallow concentrated flow segment.

Open channels

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation.

Manning's equation is

$$V = \frac{1.49\, r^{2/3}\, s^{1/2}}{n} \qquad \text{[Eq. 3-4]}$$

where

V = average velocity (ft/s),
r = hydraulic radius (ft) and is equal to a/p_w,
a = cross sectional flow area (ft^2),
p_w = wetted perimeter (ft),
s = slope of the hydraulic grade line (channel slope, ft/ft), and
n = Manning's roughness coefficient for open channel flow.

Manning's n values for open channel flow can be obtained from standard textbooks such as Chow (1959) or Linsley et al. (1982). After average velocity is computed using equation 3-4, T_t for the channel segment can be estimated using equation 3-1.

Reservoirs or lakes

Sometimes it is necessary to estimate the velocity of flow through a reservoir or lake at the outlet of a watershed. This travel time is normally very small and can be assumed as zero.

Limitations

- Manning's kinematic solution should not be used for sheet flow longer than 300 feet. Equation 3-3 was developed for use with the four standard rainfall intensity-duration relationships.

- In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate T_c. Storm sewers generally handle only a small portion of a large event. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or nonpressure flow.

- The minimum T_c used in TR-55 is 0.1 hour.

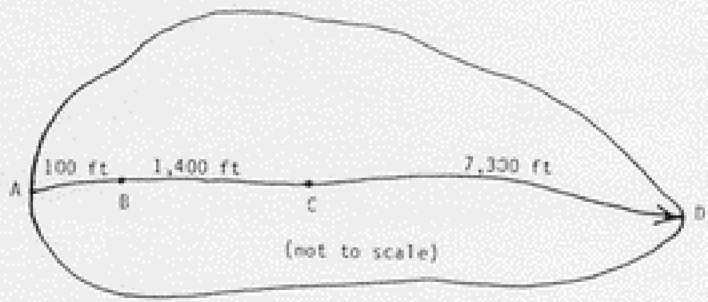
- A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. The procedures in TR-55 can be used to determine the peak flow upstream of the culvert. Detailed storage routing procedures should be used to determine the outflow through the culvert.

Example 3-1

The sketch below shows a watershed in Dyer County, northwestern Tennessee. The problem is to compute T_c at the outlet of the watershed (point D). The 2-year 24-hour rainfall depth is 3.6 inches. All three types of flow occur from the hydraulically most distant point (A) to the point of interest (D). To compute T_c, first determine T_t for each segment from the following information:

Segment AB: Sheet flow; dense grass; slope (s) = 0.01 ft/ft; and length (L) = 100 ft.
Segment BC: Shallow concentrated flow; unpaved; s = 0.01 ft/ft; and L = 1400 ft.
Segment CD: Channel flow; Manning's n = .05; flow area (a) = 27 ft^2; wetted perimeter (p_w) = 28.2 ft; s = 0.005 ft/ft; and L = 7300 ft.

See figure 3-2 for the computations made on worksheet 3.



Worksheet 3: Time of concentration (T_c) or travel time (T_t)

Project Heavenly Acres By DW Date 10/6/85

Location Dyer County, Tennessee Checked [illegible] Date 10/8/85

Circle one: Present Developed

Circle one: T_c T_t through subarea

NOTES: Space for as many as two segments per flow type can be used for each worksheet.

Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)	Segment ID	AB			
1. Surface description (table 3-1)		DENSE GRASS			
2. Manning's roughness coeff., n (table 3-1) ..		0.24			
3. Flow length, L (total L $\leq$ 300 ft)	ft	100			
4. Two-yr 24-hr rainfall, P_2	in	3.6			
5. Land slope, s	ft/ft	0.01			
6. $T_t = \frac{0.007\ (nL)^{0.8}}{P_2^{0.5}\ s^{0.4}}$ Compute T_t	hr	0.30	+		= 0.30
Shallow concentrated flow	Segment ID	BC			
7. Surface description (paved or unpaved)		Unpaved			
8. Flow length, L	ft	1400			
9. Watercourse slope, s	ft/ft	0.01			
10. Average velocity, V (figure 3-1)	ft/s	1.6			
11. $T_t = \frac{L}{3600\ V}$ Compute T_t	hr	0.24	+		= 0.24
Channel flow	Segment ID	CD			
12. Cross sectional flow area, a	ft^2	27			
13. Wetted perimeter, P_w	ft	28.2			
14. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r	ft	0.957			
15. Channel slope, s	ft/ft	0.005			
16. Manning's roughness coeff., n		0.05			
17. $V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V	ft/s	2.05			
18. Flow length, L	ft	7300			
19. $T_t = \frac{L}{3600\ V}$ Compute T_t	hr	0.99	+		= 0.99
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19)	hr				1.53

Figure 3-2.—Worksheet 3 for example 3-1.

Chapter 4: Graphical Peak Discharge method

This chapter presents the Graphical Peak Discharge method for computing peak discharge from rural and urban areas. The Graphical method was developed from hydrograph analyses using TR-20, "Computer Program for Project Formulation–Hydrology" (SCS 1983). The peak discharge equation used is

$$q_p = q_u A_m Q F_p \qquad \text{[Eq. 4-1]}$$

where

q_p = peak discharge (cfs);
q_u = unit peak discharge (csm/in);
A_m = drainage area (mi^2);
Q = runoff (in); and
F_p = pond and swamp adjustment factor.

The input requirements for the Graphical method are as follows: (1) T_c (hr), (2) drainage area (mi^2), (3) appropriate rainfall distribution (I, IA, II, or III), (4) 24-hour rainfall (in), and (5) CN. If pond and swamp areas are spread throughout the watershed and are not considered in the T_c computation, an adjustment for pond and swamp areas is also needed.

Peak discharge computation

For a selected rainfall frequency, the 24-hour rainfall (P) is obtained from appendix B or more detailed local precipitation maps. CN and total runoff (Q) for the watershed are computed according to the methods outlined in chapter 2. The CN is used to determine the initial abstraction (I_a) from table 4-1. I_a/P is then computed.

If the computed I_a/P ratio is outside the range shown in exhibit 4 (4-I, 4-IA, 4-II, and 4-III) for the rainfall distribution of interest, then the limiting value should be used. If the ratio falls between the limiting values, use linear interpolation. Figure 4-1 illustrates the sensitivity of I_a/P to CN and P.

Peak discharge per square mile per inch of runoff (q_u) is obtained from exhibit 4-I, 4-IA, 4-II, or 4-III by using T_c (chapter 3), rainfall distribution type, and I_a/P ratio. The pond and swamp adjustment factor is obtained from table 4-2 (rounded to the nearest table value). Use worksheet 4 in appendix D to aid in computing the peak discharge using the Graphical method.

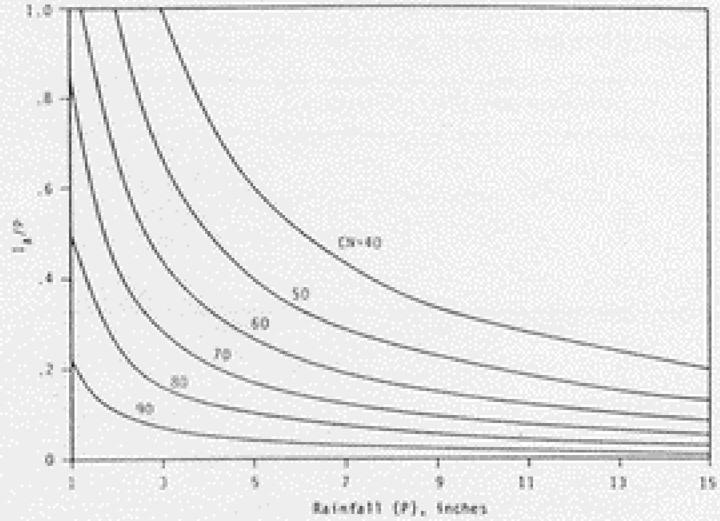


Figure 4-1.—Variation of I_a/P for P and CN.

Table 4-1.—I_a values for runoff curve numbers

Curve number	I_a (in)	Curve number	I_a (in)
40	3.000	70	0.857
41	2.878	71	0.817
42	2.762	72	0.778
43	2.651	73	0.740
44	2.545	74	0.703
45	2.444	75	0.667
46	2.348	76	0.632
47	2.255	77	0.597
48	2.167	78	0.564
49	2.082	79	0.532
50	2.000	80	0.500
51	1.922	81	0.469
52	1.846	82	0.439
53	1.774	83	0.410
54	1.704	84	0.381
55	1.636	85	0.353
56	1.571	86	0.326
57	1.509	87	0.299
58	1.448	88	0.273
59	1.390	89	0.247
60	1.333	90	0.222
61	1.279	91	0.198
62	1.226	92	0.174
63	1.175	93	0.151
64	1.125	94	0.128
65	1.077	95	0.105
66	1.030	96	0.083
67	0.985	97	0.062
68	0.941	98	0.041
69	0.899		

Table 4-2.—Adjustment factor (F_p) for pond and swamp areas that are spread throughout the watershed

Percentage of pond and swamp areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Limitations

The Graphical method provides a determination of peak discharge only. If a hydrograph is needed or watershed subdivision is required, use the Tabular Hydrograph method (chapter 5). Use TR-20 if the watershed is very complex or a higher degree of accuracy is required.

- The watershed must be hydrologically homogeneous, that is, describable by one CN. Land use, soils, and cover are distributed uniformly throughout the watershed.
- The watershed may have only one main stream or, if more than one, the branches must have nearly equal T_c's.
- The method cannot perform valley or reservoir routing.
- The F_p factor can be applied only for ponds or swamps that are not in the T_c flow path.
- Accuracy of peak discharge estimated by this method will be reduced if I_a/P values are used that are outside the range given in exhibit 4. The limiting I_a/P values are recommended for use.
- This method should be used only if the weighted CN is greater than 40.
- When this method is used to develop estimates of peak discharge for both present and developed conditions of a watershed, use the same procedure for estimating T_c.
- T_c values with this method may range from 0.1 to 10 hours.

Example 4-1

Compute the 25-year peak discharge for the 250-acre watershed described in examples 2-2 and 3-1. Figure 4-2 shows how worksheet 4 is used to compute q_p as 345 cfs.

Worksheet 4: Graphical Peak Discharge method

Project Heavenly Acres By RHM Date 10/15/85

Location Dyer County, Tennessee Checked NM Date 10/17/85

Circle one: Present Developed

1. Data:

Drainage area .... A_m = 0.39 mi^2 (acres/640)

Runoff curve number .... CN = 75 (From worksheet 2), Figure 2-6

Time of concentration .. T_c = 1.53 hr (From worksheet 3), Figure 3-2

Rainfall distribution type = II (I, IA, II, III)

Pond and swamp areas spread throughout watershed ...... = -- percent of A_m (-- acres or mi^2 covered)

		Storm #1	Storm #2	Storm #3
2. Frequency	yr	25		
3. Rainfall, P (24-hour)	in	6.0		
4. Initial abstraction, I_a .... (Use CN with table 4-1.)	in	0.667		
5. Compute I_a/P		0.11		
6. Unit peak discharge, q_u .... (Use T_c and I_a/P with exhibit 4-II)	csm/in	270		
7. Runoff, Q .... (From worksheet 2). Figure 2-6	in	3.28		
8. Pond and swamp adjustment factor, F_p .... (Use percent pond and swamp area with table 4-2. Factor is 1.0 for zero percent pond and swamp area.)		1.0		
9. Peak discharge, q_p .... (Where $q_p = q_u A_m Q F_p$)	cfs	345		

Figure 4-2.—Worksheet 4 for example 4-1.

Exhibit 4-I: Unit peak discharge (q_u) for SCS type I rainfall distribution

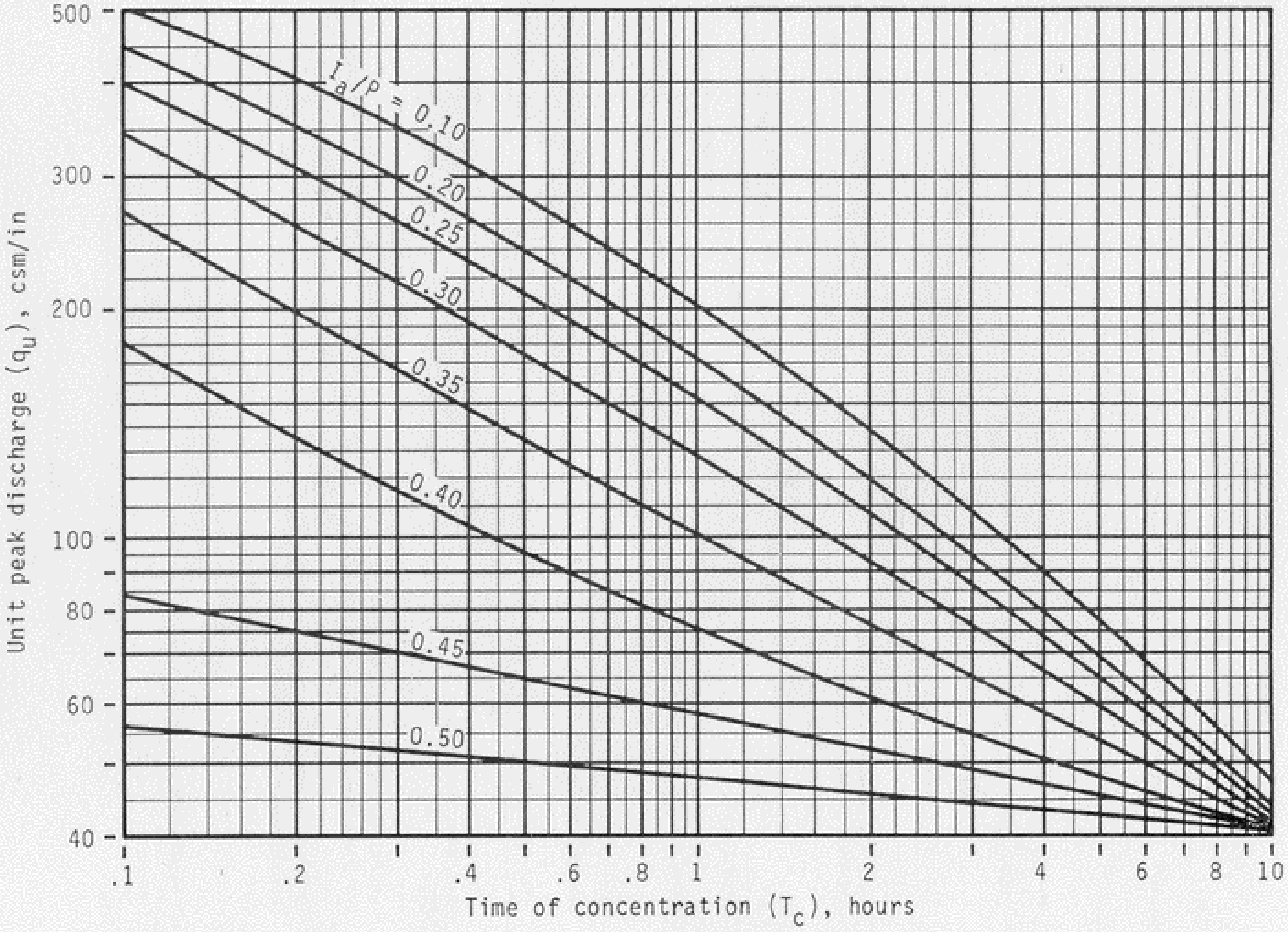


Exhibit 4-IA: Unit peak discharge (q_u) for SCS type IA rainfall distribution

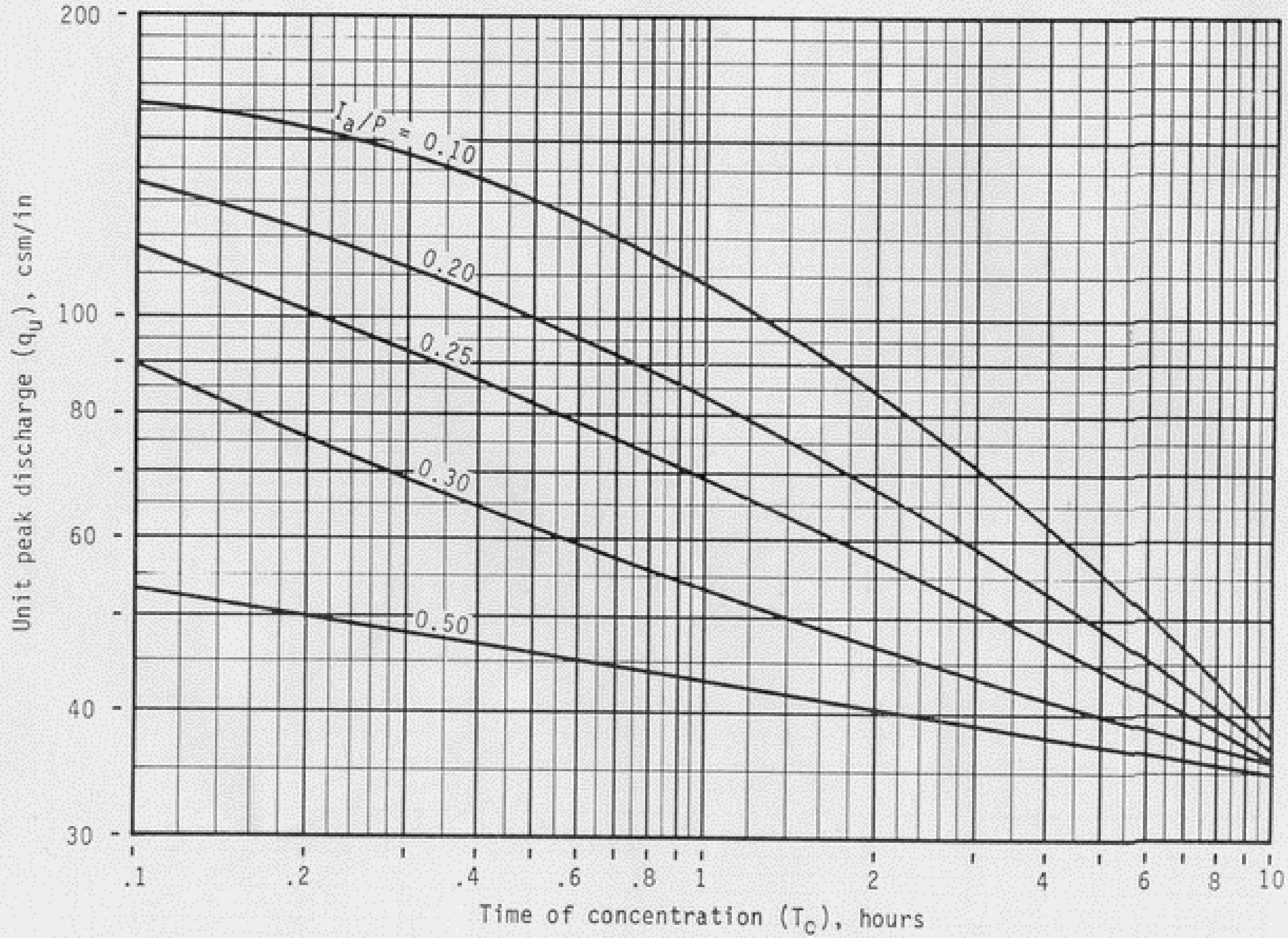


Exhibit 4-II: Unit peak discharge (q_u) for SCS type II rainfall distribution

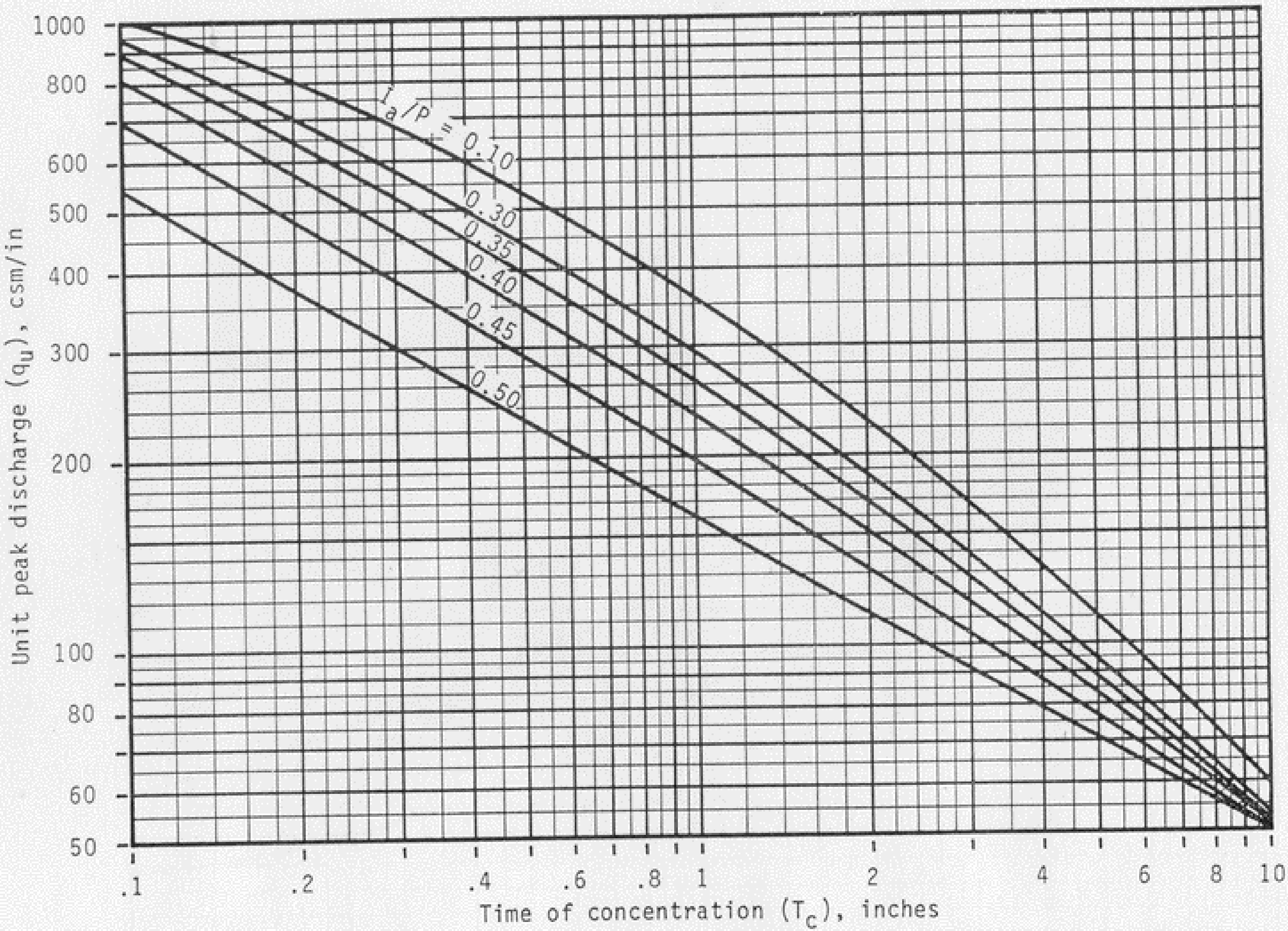
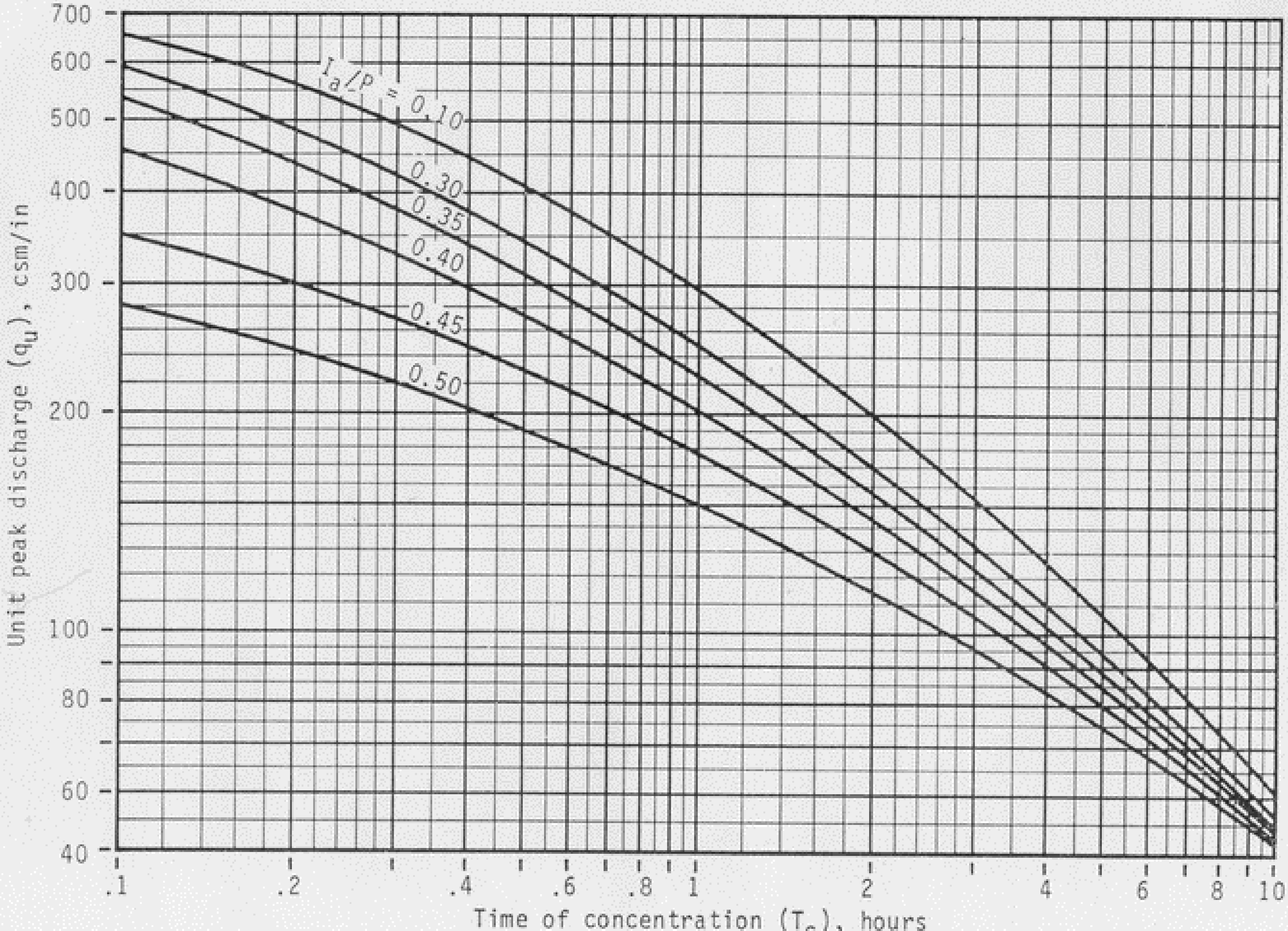


Exhibit 4-III: Unit peak discharge (q_u) for SCS type III rainfall distribution



Worksheet 2: Runoff curve number and runoff

Project ______________________ By ______ Date ______

Location ______________________ Checked ______ Date ______

Circle one: Present Developed ______________________

1. Runoff curve number (CN)

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 2-2	CN 1/ Fig. 2-3	CN 1/ Fig. 2-4	Area ☐ acres ☐ mi^2 ☐ %	Product of CN x area
				Totals =		

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}}$ = ______ = ______; Use CN = ☐

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr			
Rainfall, P (24-hour)	in			
Runoff, Q .... (Use P and CN with table 2-1, fig. 2-1, or eqs. 2-3 and 2-4.)	in			

Worksheet 3: Time of concentration (T_c) or travel time (T_t)

Project ______________________ By _____ Date ________

Location ______________________ Checked _____ Date ________

Circle one: Present Developed ______________________

Circle one: T_c T_t through subarea ______________________

NOTES: Space for as many as two segments per flow type can be used for each worksheet.

Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)		Segment ID			
1. Surface description (table 3-1)					
2. Manning's roughness coeff., n (table 3-1) ..					
3. Flow length, L (total L $\leq$ 300 ft)	ft				
4. Two-yr 24-hr rainfall, P_2	in				
5. Land slope, s	ft/ft				
6. $T_t = \frac{0.007\ (nL)^{0.8}}{P_2^{0.5}\ s^{0.4}}$ Compute T_t	hr		+		=

Shallow concentrated flow		Segment ID			
7. Surface description (paved or unpaved)					
8. Flow length, L	ft				
9. Watercourse slope, s	ft/ft				
10. Average velocity, V (figure 3-1)	ft/s				
11. $T_t = \frac{L}{3600\ V}$ Compute T_t	hr		+		=

Channel flow		Segment ID			
12. Cross sectional flow area, a	ft^2				
13. Wetted perimeter, p_w	ft				
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r	ft				
15. Channel slope, s	ft/ft				
16. Manning's roughness coeff., n					
17. $V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V	ft/s				
18. Flow length, L	ft				
19. $T_t = \frac{L}{3600\ V}$ Compute T_t	hr		+		=

20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) .... hr

Worksheet 4: Graphical Peak Discharge method

Project ______________________ By ____ Date ______

Location ______________________ Checked ____ Date ______

Circle one: Present Developed ______________________

1. Data:

Drainage area .... A_m = ________ mi^2 (acres/640)

Runoff curve number .... CN = ________ (From worksheet 2)

Time of concentration .. T_c = ________ hr (From worksheet 3)

Rainfall distribution type = II (I, IA, II, III)

Pond and swamp areas spread throughout watershed ...... = ________ percent of A_m (____ acres or mi^2 covered)

		Storm #1	Storm #2	Storm #3
2. Frequency	yr			
3. Rainfall, P (24-hour)	in			
4. Initial abstraction, I_a .... (Use CN with table 4-1.)	in			
5. Compute I_a/P				
6. Unit peak discharge, q_u .... (Use T_c and I_a/P with exhibit 4-II)	csm/in			
7. Runoff, Q .... (From worksheet 2). Figure 2-6	in			
8. Pond and swamp adjustment factor, F_p .... (Use percent pond and swamp area with table 4-2. Factor is 1.0 for zero percent pond and swamp area.)				
9. Peak discharge, q_p .... (Where $q_p = q_u A_m Q F_p$)	cfs			

Figure 4-2.—Worksheet 4 for example 4-1.